Application Bulletin AB-8

Selection of MOSFETs in Switch Mode DC-DC Converters

Introduction

This application bulletin is intended to give the system designer guidelines for choosing the optimum power MOSFET to be used with Fairchild's family of DC-DC converter controllers. The optimum MOSFET choice will be that which meets all of the system requirements at the smallest component cost.

System Requirements

System requirements that have the strongest influence on MOSFET selection are:

1. Load current, I_{load}, since this directly affects the MOSFET power dissipation;
2. The system input and output voltages, which determine the MOSFET duty cycle;
3. Switching frequency, F_s , which the affects the power dissipated during the switching transition time; and
4. Maximum allowed operating temperature of the MOSFET, which is usually specified to meet a long term reliability goal for the system.

MOSFET Design Choices

Once the operating conditions of the system have been determined (load current, frequency, V_{out}, etc.), the choices for the power MOSFET design are the following:

1. The value of $R_{DS(on)}$. The lower the value, the less dissipation and the better the system will work. However, lower resistance MOSFETs will cost more than higher resistance devices.
2. Heat Sink. If space is available, external heat sinks can achieve the same results as a lower $R_{DS(on)}$ at a lower cost. It may also be possible to use surface mount MOSFETs; further details on their usage may be found in Application Bulletin 15.
3. Multiple MOSFETs. Sometimes the same operating temperature can be achieved at a lower price with two higher value $R_{DS(on)}$ MOSFETs connected in parallel, if board space permits.

Calculating Power Dissipation and MOSFET Case Temperature

There are three components of power dissipation during operation:

1. The power dissipation when the MOSFET is turned fully on :

   $P_{on} = I_{load}^2 \times R_{ds(on)} \times$ duty cycle where I_{load} is the maximum DC output current;

2. The power dissipation during the turn on transition:

   $$P_{tr,on} = \frac{I_{load} \times V_{DS} \times T_r \times F_s}{2}$$

   where T_r is the rise time of the MOSFET's drain, V_{DS} is the drain-source voltage (see below), and F_s is the switching frequency;

3. The power dissipation during the turn off transition:

   $$P_{tr,off} = \frac{I_{load} \times V_{DS} \times T_f \times F_s}{2}$$

   where T_f is the fall time of the MOSFET.

Duty cycle in continuous mode switching regulators = V_{out}/V_{in}. V_{DS} is the maximum voltage between the drain and the source. For a nonsynchronous converter, $V_{DS} = V_{in} + V_f$, with V_f the forward voltage of the schottky diode. For a sunchronous converter, the high-side MOSFET has a $V_{DS} = V_{in}$, while the low-side MOSFET has $V_{DS} = V_f$.

We can now calculate the MOSFET's temperature. The junction temperature of the device will be $T_A + (P_D \times \theta_{CA})$ or $T_A + (P_D \times \theta_{SA})$ where P_D is the power dissipation (the sum of factors 1, 2 and 3 above), θ_{CA} is the thermal coefficient of case to ambient and θ_{SA} is the thermal coefficient from heat sink to ambient. These formulae assume that the thermal coefficient from junction to case (~1°C/W) is negligible in comparison with the other thermal resistances.

Specifications for Typical MOSFETs

Table 1 is a listing of $R_{DS(on)}$ and thermal resistance for commonly used MOSFETs tabulated from published data sheets. Notice that there is a considerable range in $R_{DS(on)}$ values.

The thermal resistance is listed for operation without a heat sink and can be significantly reduced by the addition of a heat sink.

Table 1: MOSFET Selection Table

Manufacturer and Part #	Conditions		$R_{DS,ON}$ (mΩ)		Package	Thermal Resistance (°C/W)
			Typ.	Max.		
Fairchild FDP6030L	V_{GS} = 4.5V, I_D = 21A	T_J = 25°C	15	20	TO-220	Θ_{JA} = 62.5
Fairchild FDB6030L	V_{GS} = 4.5V, I_D = 21A	T_J = 25°C	15	20	D^2PAK	Θ_{JA} = 62.5
Fairchild FDP603AL	V_{GS} = 4.5V, I_D = 10A	T_J = 25°C	30	36	TO-220	Θ_{JA} = 62.5
Fairchild FDB603AL	V_{GS} = 4.5V, I_D = 10A	T_J = 25°C	30	36	D^2PAK	Θ_{JA} = 62.5
Fairchild FDP7030L	V_{GS} = 5V, I_D = 40A	T_J = 25°C	9	10	TO-220	Θ_{JA} = 62.5
Fairchild FDB7030L	V_{GS} = 5V, I_D = 40A	T_J = 25°C	9	10	D^2PAK	Θ_{JA} = 62.5
IR IRL2203N	V_{GS} = 4.5V, I_D = 50A	T_J = 25°C		10	TO-220	Θ_{JA} = 62
IR IRL2203S	V_{GS} = 4.5V, I_D = 50A	T_J = 25°C		10	D^2PAK	Θ_{JA} = 40

Recommendations for Choosing the Lowest Cost MOSFET

There is no simple way to pick the lowest cost MOSFET and heat sink combination because there are many design choices that go into a motherboard converter system design. However, the Excel spreadsheet in Table 2 will give the motherboard designer an easy way to analyze all the choices involved and help make the right performance and cost tradeoffs. The spreadsheet has been embedded and can be used in electronic versions of this application bulletin. The spreadsheet shows the selection process for two options: 1) Fairchild FDP7030L MOSFETs for both high-side and low-side, and 2) Fairchild FDP6030L MOSFETs for both high-side and low-side. The spreadsheet entries and formulas are explained below by line:

1. The $R_{ds(on)}$ value of the high-side MOSFET from the MOSFET data sheet.
2. FET rise time from the data sheet.
3. FET fall time from the data sheet. The designer should note that the numbers in the datasheet for MOSFET rise and fall times may be as much as double what is actually observed, and so the losses due to switching time may be considerably less than those calculated here.
4. The $R_{ds(on)}$ value of the low-side MOSFET from the MOSFET data sheet.
5. Maximum load current for the application.
6. The worse case ambient temperature. For this example, 40°C.
7. Maximum case temperature. This is based on the long term reliability goals for the design but typically does not exceed 100°C.
8. The value for the regulator's switching frequency. Although higher switching frequencies result in more dissipation, this value is determined by other factors such as output current transient response. Typical values for motherboard applications range between 200 and 300kHz.
9. Input voltage for the FET. This is almost always either 5V or 12V.
10. V_{out} for the regulator. The values of V_{out} and V_{in} determine the duty cycle.
11. Duty cycle. This is a calculated field. The duty cycle is $(1 - V_{in}/V_{out})$ for a low-side MOSFET.
12. Total high-side MOSFET power dissipation. This calculation includes the power from both the switching transitions plus the power dissipated during the on time.
13. Total low-side MOSFET power dissipation.
14. Thermal resistance. This calculation shows how much heatsinking is needed to achieve the maximum case temperature for the high-side MOSFET given all the conditions listed above.

15. Heatsink Recommendation for the high-side MOSFET. This field gives a typical heatsink meeting the thermal resistance requirement. Note that this field is not calculated, and must be manually entered for each case.

16. Thermal resistance for the low-side MOSFET.

17. Heatsink Recommendation for the low-side MOSFET.

Again, the designer should note that these numbers are worst-case.

Table 2: Heat Sink Requirement Spreadsheet

Upper MOSFET		**FDP7030L**	**FDP6030L**
1	Rds(on) (mΩ)	10	20
2	tr (nsec)	340	150
3	tf (nsec)	110	17
	Lower MOSFET	**FDP7030L**	**FDP6030L**
4	Rds(on) (mΩ)	10	20
5	Load Current (A)	12.6	12.6
6	Tamb,max (C)	40	40
7	Tcase,max (C)	100	100
8	Freq (kHz)	300	300
9	Vin (V)	5	5
10	Vout (V)	2.0	2.0
11	Duty Cycle	0.4	0.4
12	Power, Upper (W)	5.18	3.42
13	Power, Lower (W)	1.38	2.77
	For TO-220s:		
14	Heatsink, Upper (C/W)	12	18
15	Suggested Heatsink:	#581201	#576802
	(Aavid)		
16	Heatsink, Lower (C/W)	43	22
17	Suggested Heatsink:	None	#576802
	(Aavid)		
	For TO-263a: Must be mounted with minimum recommended pad size.		

The decisions that are derived from Table 2 will vary greatly depending on the application. For the above example, a 12.6A application was chosen (corresponding to a 400MHz Pentium II). Because heatsinks that achieve a thermal resistance lower than 20°C/W can get bulky, in some circumstances it may be desirable to double the number of FETs. To treat this case, enter half the value of the $R_{ds(on)}$ into fields 1 and/or 4, and then divide the resulting numbers in fields 14 and/or 16 respectively by two. For most current designs, it sppears most economical to use, for example, a single FDP6030L for both high-side and low-side and a heatsink.

For the use of surface-mount MOSFETS, the user should note that even with two IRL2203Ss, despite their low $R_{ds(on)}$ and Θ_{JA}, it may be difficult to keep the MOSFETs cool enough, because it is difficult to attach heatsinks to surface mount components. Instead, the thermal resistance is determined by the pad size. For further information on this, refer to Application Bulletin 15.

The optimization shown here will yield quite different results from the example shown here for very different output current levels or for 12V input applications.

Conclusions

The formulas needed to design a safe operating power MOSFET application have been presented, as well as a spreadsheet tool that can help optimize the cost tradeoffs in the design.

Notes:

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